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BOUNDS ON THE WEAK MESON-NUCLEON COUPLINGS FROM PARITY VIOLATING EFFECTS IN NONLEPTONIC NUCLEAR PROCESSES

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Abstract

The implications of the existing experimental and theoretical information on the p.v. meson-nucleon coupling constants are investigated.

Parity-violating effects have been observed in numerous nonleptonic nuclear processes. It is generally believed that they are manifestations of the first-order $\Delta S = 0$ nonleptonic weak interactions, expected in modern theories of the weak interactions. Their dominant effect in nuclear systems is a p.v. contribution to the NN interaction. It is expected (with reservations for possibly important contributions from two pion-exchange) that for low-energy processes the latter can be well represented by a potential stemming from the exchange of single pseudoscalar and vector mesons: the $\pi^{\pm}$, $\rho^{\pm,0}$ and the ω. Apart from the 5 strong coupling constants ($g_{\pi NN}$, $g_{\rho NN}$, μ_ρ, $g_{\omega NN}$ and μ_ω), this potential contains 7 effective coupling constants[1], which we shall denote ρ_0, ρ_1, $\rho_1^\dagger$, ρ_2, ω_0, ω_1 and f_π, describing (in units of 10^{-6}) the p.v. NNM vertices[2]. The p.v. coupling constants, through which the p.v. Hamiltonian enters are the quantities to be deduced from experiment to confront predictions based on weak interaction theory. The purpose of the present study is to examine the extent to which they can be determined on the basis of the existing experimental information and the available calculations.

Calculations of low-energy p.v. observables have been carried out using directly the p.v. NN potential and assuming a model for the short distance behavior of the strong NN interaction[3], or in an approach pioneered by Desplanques and Missimer[5], which starts from an effective two-body potential parameterized in terms of the p.v. NNπ coupling constant and the 5 zero-energy NN scattering amplitudes for SP transitions, and which therefore incorporates the effects of the short range behavior of the strong NN interaction. In this paper we shall discuss the implications of the DM calculations.[5] Among complex nuclei, calculations which start from the p.v. meson-exchange potential have been carried out in sufficient generality only for ^{18}F, ^{19}F and ^{21}Ne. We note that predictions for these nuclei differ considerably from those of DM, pointing to the need for further theoretical work. A discussion of the implications of these differences will be postponed to Ref. 6.

Desplanques and Missimer presented results for 10 p.v. observables in terms of their 6 parameters.[7] To relate the DM parameters to the NNM coupling constants, we used the calculations of McKellar and Lassey,[4] assuming the Reid-Pieper soft core potential for the strong NN interaction. Since this relationship maps 3 isovector NNM coupling constants (ρ_1, ω_1, and $\rho_1^\dagger$) into two ΔI=1 S-P transition amplitudes, there is one linear combination of the NNM constants which remains undetermined. $g_{\omega NN}$, which is not well known, has been left as a free parameter. For μ_ω the "canonical" value $-.12$ had to be used since it is incorporated in the calculations of Ref. 3. We took $g_{\rho NN} = 5.4$ and $\mu_\rho = 3.7$.

The goal of our analysis is to determine values or bounds for the p.v. NNM coupling constants from consistent subsets of data, with no a priori assumptions on their possible size, and with constraints imposed as discussed below. Thus the ideal choice of the parameters to carry out the analysis would be the linear combinations of the NNM constants, which are the eigenvectors of the measurement matrix. The latter are statistically independent and constraining some of them would not therefore influence the values determined for others. On the other hand, the eigenvectors of the measurement matrix involve in general NNM constants corresponding to all isospin components of the p.v. Hamiltonian. As it is of interest to seek information on quantities associated with the individual isospin components, only those orthogonal transformations of the seven NNM constants were admitted which do not mix the subspaces corresponding to different values of isospin. In addition, we have also separated the p.v. NNπ coupling constant from the I=1 vector meson ones, because its contribution to the p.v. observables is free of the uncertainties in the short-distance behavior of the strong NN interaction. The resulting lin. combinations, determined using the measurement matrix of all 10 data are $\tilde{f}_\pi$, ρ_2, $A_0 = -.65\hat{\omega}_0 + .76\rho_0$, $B_0 = .76\hat{\omega}_0 + .65\rho_0$, $A_1 = -.68\hat{\omega}_1 - .69\rho_1 - .22\rho_1^\dagger$, $B_1 = -.39\hat{\omega}_1 + .61\rho_1 - .69\rho_1^\dagger$ and $C_1 = -.62\hat{\omega}_1 + .39\rho_1 + .68\rho_1^\dagger$, where $\hat{\omega}_{0,1} = \omega_{0,1}\, g_{\omega NN}/g_{\rho NN}$. Inspection of the eigenvalues shows that $A_0(A_1)$ is better determined than $B_0(B_1)$ and identified C_1 as the undetermined combination. When fewer data are included, $A_0(A_1)$ will still be better determined than $B_0(B_1)$, since the coefficients of the latter are small in most of the observables.

It has proven useful for discussing the consistency of the data to divide them into the following four groups: (A) $\equiv$ p.v. effects in ^{18}F, ^{19}F, $\vec{p}$p scattering, ^{16}O and in $\vec{n}$+p $\to$ d+γ; (B) $\equiv$ circ. polarization in ^{21}Ne; (C) $\equiv$ circ. polarization in n+p $\to$ d+γ and (D) $\equiv$ circ. polarizations in ^{41}K, ^{175}Lu and ^{181}Ta. The results of various fits are shown in Table I.[8] The following conclusions can be drawn: 1) Considering the group (A) alone, the additional parameter, which is undetermined turns out to be approximately equal to B_0. Inspection shows that B_1 can be neglected, as long as $|B_1| < 100$. The resulting 4-parameter fit shows that set (A) does not require and I=1 or I=2 p.v. interaction. The data can be explained by one isoscalar parameter, a one parameter fit yielding $A_0 = 2.2 \pm .2$ ($\chi^2 = 0.9/5-1$). At the same time, the heavy elements (set D) are predicted to have the right sign and be about a factor of two too low in magnitude. The above value of A_0 is fixed by the ^{16}O experiment and consequently it is subject to the uncertainties in the corresponding calculations. 2) Inclusion of the circ. polarization in n+p $\to$ d+γ leads to a good χ^2. A large value of ρ_2 is required, as suggested first by McKellar.[9] Provided that $|B_0| < 800$, there is no way to explain this experiment without a large ρ_2. The large value of ρ_2 induces in turn a large A_1 (to cancel the effect of ρ_2 in A_{pp}) and an appropriate $\tilde{f}_\pi$ (to cancel the effect of A_1 in ^{18}F). 3) The fit to (A) + (D) gives essentially the same results as the fit to (A) + (C). However, here the evidence for a large ρ_2 must be viewed with caution, since it depends on the precise quantitative correctness of the nuclear structure calculation for the heavy elements and/or for ^{16}O. 4) ^{21}Ne is inconsistent with (A) ($\chi^2 = 21/6-4$; $\chi^2 = 7.7/6-5$). The fitted value of ^{16}O is too small by ~3 standard deviations and the fitted value of ^{21}Ne is too large by ~3 standard deviations. 5) The fit to all data excluding ^{21}Ne has a marginally acceptable χ^2 and leads to values of A_0 and $\tilde{f}_\pi$ consistent with general theoretical expectations and in particular with the bounds predicted by Desplanques, Donoghue and Holstein[10] in a quark-model approach.[11] However the required value of ρ_2 (and probably also of A_1) seems to be too large to be understood in terms of the weak interactions. As discussed before, this last statement becomes serious only if the result for the circ. polarization in $n+p \rightarrow d+\gamma$ is confirmed. 6) There exists a good

Table I. Summary of Least Squares Fits to Subsets of Experimental Data. M(N) is the number of measurements (adjusted parameters) included in the fit. P is the probability that a value of χ^2 larger than the quoted one will occur through random fluctuations.

Data Set	A	A+C	A+C	A+D	A+C+D	A+C+D
χ^2/M-N	.07/5-4	0/6-6	1.9/6-4	8.0/8-4	6.2/9-6	8.2/9.4
P	.80	------	.33	.09	.10	.14
Quality	Good	------	Good	Marginal	Marginal	Marginal
A_0	2.2(.2)	-1(13)	2.2(.2)	2.2(.2)	1.5(.5)	2.2(.2)
B_0	< 260	-4300(14000)	< 190	< 260	-810(570)	< 230
A_1	5(18)	390(1400)	27(10)	26(12)	50(22)	30(9)
B_1	100	2100(7700)	< 40	< 50	240(180)	< 40
$\tilde{f}_\pi$	- .6(2.1)	-33(120)	-2.9(1.1)	-2.7(1.3)	-4.2(1.8)	-3.2(1.0)
ρ_2	4(15)	-170(640)	20(8)	20(9)	-10(25)	24(7)

2-parameter fit to set (A) which includes $\tilde{f}_\pi$, if one sets the following bounds for the other parameters: $|B_0| < 180$, $|B_1| < 22$, $|A_1| < .9$ and $|\rho_2| < 9$. These are consistent with those given in Ref. 10 for both the Cabibbo model and the Weinberg-Salam model, provided $|\rho_t^*| < 4$ (with $g_{\omega NN}/g_{\rho NN} < 2$ assumed). For this hypothesis we find $\chi^2 = 0.9/5-2$ and $A_0 = 2.2 \pm .2$, $\tilde{f}_\pi = 0.02 \pm 0.09$. These values of A_0 and $\tilde{f}_\pi$ fall within the predicted bounds of Ref. 10, but lead to predictions for the p.v. observables in group D which agree with experiment only within a factor of two. The circular polarization in $n+p \rightarrow d+\gamma$ is unexplained.

The above results refer to the Reid-Pieper soft-core potential assumed for the strong NN interaction. We have also investigated the effects of using instead the expressions for the DM parameters calculated with the super-soft core potential of Gogny, Pires and deTourreil.[3] We find that the quality of the fits remains essentially unchanged, the only effect being the decrease in magnitude of the p.v. vector-meson coupling constants by about a factor of two. As expected, the value of $\tilde{f}_\pi$ is not altered.

*Work performed under the auspices of the U. S. DOE.

References

1) M. Chemtob and B. Desplanques, Nucl. Phys. B78, 139 (1974).
2) Our p.v. coupling constants are defined by (see also Ref. 6) $\Lambda^{i}_{j,m} \equiv \langle Nm^{i} | H^{p.v.}_{I=j} | p \rangle = m_j \bar{u}_N [\gamma^\mu \gamma_5 + \ldots] u_p \epsilon^{(m)}$ (N = n or p) for $(jmI) = (0,\rho,+), (1,\rho,0), (2,\rho,+), (0,\omega,0)$ and $(1,\omega,0)$; furthermore, $\Lambda^{+}_{1,\pi} + \tilde{f}_\pi \bar{u}_n u_p$ and $\Lambda^{+}_{1,\rho} = \rho^{+}_{1} \bar{u}_n [i\sigma^{\mu\nu}(p_n \quad p_p)_\nu / 2M] u_p$. The Bjorken-Drell conventions were adopted. On the basis of experience with $\Delta S = 1$ nonleptonic weak interactions one could expect $\rho_0, \omega_0, \ldots$ to be of order G'/G (the constants describing $\Delta I = 0,1$ transitions perhaps as large as $6\ G'/G$ and ρ_2 somewhat smaller than G'/G), where G' is the coupling constant involved in the corresponding $\Delta S = 0$ Hamiltonian, and $Gm_\rho^2 \cong 10^{-5}$.
3) B. H. J. McKellar, Proc. Vancouver Conf. on N-N Interactions, 1977, AIP Conf. Proc. No. 41, p. 432.
4) B. H. J. McKellar, Ref. 3 and private communication.
5) B. Desplanques and J. Missimer, Nucl. Phys. A300, 286 (1978).
6) A detailed account of this work will be published elsewhere.
7) B. Desplanques and J. Missimer, to be published.
8) In Table I an inequality for a given parameter represents an imposed constraint on its absolute value, which guarantees that setting it to zero will not change the values of any other parameters by more than a standard deviation. We use such constraints when the inclusion of a very poorly determined parameter would lead to large uncertainties in some other parameters. Note the comparison between the two (A) + (C) fits in Table I.
9) B. H. J. McKellar, Nucl. Phys. A254, 349 (1975).
10) B. Desplanques, J. F. Donoghue and B. R. Holstein, MIT Preprint, 1979, to be published.
11) The values of Λ_0 and $\tilde{f}_\pi$ are consistent with both the bounds predicted for the Cabibbo model and those for the Weinberg-Salam model.